Bringing optimal feedback controller design to practice

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1 Introduction

Although optimal feedback controller design based on $\mathscr{H}_\infty$ or $\mathscr{H}_2$ criteria [1] has already proven its potential in academia, it has yet to find wide acceptance in industry. One explanation is the lack of software support for practitioners without expertise in optimal control. Matlab's robust control toolbox [2] contains the core tools for $\mathscr{H}_\infty$ and $\mathscr{H}_2$ control, but (i) it doesn't allow for an easy and intuitive control problem formulation; (ii) it doesn't support multi-objective controller designs; (iii) it doesn't allow for unstable [3] or improper weights. To overcome these drawbacks we are developing a Matlab toolbox that combines an intuitive control problem formulation with efficient and numerically stable algorithms that overcome the drawbacks mentioned above.

2 Control problem formulation

In order to simplify multi-objective feedback controller design, a novel intuitive LTI problem parser is being developed. It is intended to be as simple as *sysic* and as flexible as *iconnect*. Moreover, it is designed specifically to easily impose control objectives. Some example code is depicted in figure 1. The generalized plant is constructed by connecting several subsystems. Next the control specifications are expressed in terms of a weight on a certain transfer function. Combining both gives rise to a general multi-objective control problem, which is then analyzed and solved. Future work includes the introduction of even higher level specifications for the controller design, e.g. 'maximize bandwidth' or 'add sufficient damping'.

```
lti_begin()
   % Object declaration
   subsystem G, signal r
   % Connection declaration
   u = Gin; y = Gout; e = r - y;
   % Input-output declaration (GP)
   control_in([u]); control_out([e]);
   exog_in([r]); exog_out([y]);
   % Control problem formulation
   ctrl_begin()
      minimize(WS*(e/r))
      MS*(e/r) <= 1
      WT*(y/r) <= 1
   ctrl_end
lti_end
```

Figure 1: Multi-objective control problem formulation using the new LTI Toolbox' syntax.

3 Control problem solution

Traditional multi-objective controller design uses weights to shape the closed loop behavior of the system. These weights are typically chosen to be proper since it simplifies the construction of the augmented plant. However, if the transfer function of interest is proper and of relative degree d, it is possible to add an improper weight with a zero-pole excess up to d, without making the augmented plant improper. This reduces the order of the resulting controller because poles, intended to make weights proper and typically of high frequency, can be omitted.

Adding an improper weight might result in an improper generalized plant which is modeled using a descriptor form (1):

$$E\dot{x} = Ax + Bu, \quad y = Cx + Du \tag{1}$$

Current solvers cannot deal with the descriptor form, making it impossible to add improper weights with a zero-pole excess larger than d. However, this may be necessary in order to obtain the desired roll-off in e.g. the complementary sensitivity function. To this end, future research will go to the extension of multi-objective feedback controller design to improper generalized plants.

The descriptor form also holds potential to increase the numerical conditioning of the optimization problem. Up till now only systems with unity E were valid. However allowing E to be different from unity and thus making its conditioning worse, may result in a better conditioning of A and a better conditioning of the overall LMI problem. Research will therefore focus on the optimization of the numerical conditioning of the LMI problem through appropriate transformation of A and E.

References

[1] C. Scherer, P. Gahinet and M. Chilali, "Multiobjective output-feedback control via LMI optimization," Automatic Control, IEEE Transactions on, Vol. 42, 7, 896–911, 1997.

[2] http://www.mathworks.com/help/robust/

[3] H. Köroğlu, "$\mathscr{H}_\infty$ synthesis with unstable weighting filters: An LMI solution," Decision and Control (CDC), 2013 IEEE 52nd Annual Conference on, 2429–2434, 2013.

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